A PRELIMINARY REPORT ON SOME GENETIC EXPERIMENTS CONCERNING EVOLUTION

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THE nature of the gene, the variability of factors and the effects of selection are favorite topics of recent discussion, which is well known to geneticists. The latest publications of Jennings and Castle will stir up anew the uncompromising parties and lead to new discussions. We think it advisable, therefore, to give a brief account of certain parts of a very large body of work on fundamental questions of evolution which we have carried on during the past nine years, with the collaboration of Dr. Seiler and Dr. Poppelbaum. Although some parts of the work have been finished for some years, we do not intend to publish a full account until all the details are worked out. But as certain results have already allowed us to form definite views in regard to some fundamental questions of evolution, we may present them, together with examples of the experiments in question.

The majority of the experimental work in regard to the fundamental problems of evolution has been done with domesticated animals and their mutations (rats, *Drosophila*) or with Protozoa, which present the complication of asexual reproduction. We have directed our attention to experimental analysis of such phenomena in nature, which must give basic information about evolution, and we have studied the following phenomena:

1. *The Geographic Variation of the Gypsy-moth.*—This well-defined species is spread over a great part of the globe. In different habitats, however, different races are found. How many of these exist can not be stated, but the number must be extraordinarily large, as we know but two localities where the same race is found. We have found all the races to be perfectly fertile with each other, with the exception of one combination which has never been successful. We have studied and are still studying the genetics of a large number of these races.

2. *The Melanism of the Nun-moth, Lymantria monacha.*—The nun is one of the moths which have developed melanic varieties within recent times; and these melanic varieties, which were extreme rarities not many decades ago, have almost supplanted the original white form. We have worked out the genetics of this case and shall publish the details when conditions permit. Some of the results were read before the German Zoological Society in 1911 but no abstract was published.

3. *The Genetics of Alpine Varieties, especially of Parasemia plantaginis and the Italian Races of Callimorpha dominula.*—This work has been broken off by the war, but some of the first results are available.

We shall begin with a few facts concerning the geographic variation of the gypsy-moth. We have here a form that is spread all over Europe, through Siberia into China, and all over Japan, infesting, furthermore, part

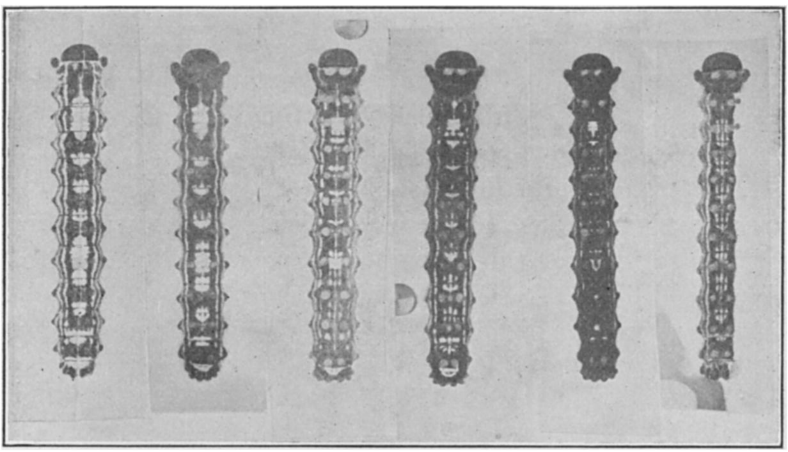

FIG. 1. Types of Caterpillars from different races after the first moult. Drawings by Mr. Yokoyama, Tokyo, 1914.

of the Atlantic coast of the United States. We have studied races from different parts of Europe and Japan and the Massachusetts form and we have found different forms in comparatively near-lying regions. Thus the races from the Rhineland, Silesia and Hungary are dif-

ferent from each other and from the Massachusetts race (probably imported from France). All of them are different from the Japanese races and these again differ in the different parts of Japan. The characters of difference are manifold; we shall confine ourselves here to a single character, more interesting and more characteristic than the others—the markings of the caterpillars. Fig. 1 shows caterpillars of a few races after the first moult. We see here some of the transitional stages from a very light to an almost black caterpillar. The genetic study of this character of marking shows that we are dealing here with a primary type of marking which belongs to the entire group of moths in a similar form, that is, the light pattern. All the darker forms have the same genetic basis of marking, on which, however, dark pigment encroaches increasingly until the markings practically disappear. We may now divide this increasing melanism into ten classes and place the lightest individuals in Class X and the ones without marking in Class I. It must be added that the dark series extends beyond Class I, but the difficulty of classifying them is such that no darker classes have been adopted.

The young caterpillars of the different races show markings which fluctuate around a mean at a certain point of the series and this behavior is remarkably constant for the different races. The following Table I gives a few polygons for different European and Japanese races.

TABLE I

CLASS FREQUENCIES IN PER CENT.

Breed	Race	I	II	III	IV	V	VI	VII	VIII	IX	X
WA3......	H	..	..	..	..	..	..	..	38.6	54.5	6.9
UA24......	K	..	..	..	..	..	..	15	64.7	20.3	..
UA17......	F	..	..	..	..	..	1.5	60	38.5	..	..
VA2.......	O	..	..	..	..	..	8.2	48.8	31.4	11.6	..
VA8.......	G	..	..	..	..	..	..	11.8	57	31.2	..
WA4......	A	..	..	..	..	19	43	38	..	..	..
WA1a......	S+	..	5.4	19.1	44	30.2	1.3	..	..	..	..
WA56......	M, S	100			..	..	..	..	..	..	..

In crosses of these different types F_1 is about intermediate, as some curves in Table II show.[1]

TABLE II

F_1. Class Frequencies in Per Cent.

Breed	Cross	1	II	III	IV	V	VI	VII	VIII	IX	X
VA17......	S × K	..	..	..	..	17.3	29.6	39.9	13.2	..	..
VA18......	K × S	..	..	..	9.2	33.3	14.4	42.2	0.9	..	..
VA21......	S × A	..	..	..	..	45.4	28.7	25.9	..	..	..
VA22......	A × S	9	20	29	11	15	13	3	..	..	..
VA23......	S × O	..	..	..	4.7	67.4	27.9	..	..	..	..
VA24......	O × S	..	..	..	..	9.9	66.9	22.4	0.8	..	..
VA37......	K × H	..	..	..	..	..	0.7	..	49.6	49	0.7
WA83......	G × M	..	..	2	24	34	32	8	..	..	..
WA88......	M × A	..	..	..	10	70	20	..	..	..	..

And F_2 gives a 1:2:1 ratio, or 3 light + medium : 1 dark, whatever races are involved. (This statement should be taken only on its face value. As a matter of fact, we find here, within the invariably present ratio of 3:1, very strange details of the kind described as "gametic contamination," and, furthermore, an obscuring of the ratio in earlier stages followed later by the right ratio, apparent lack of segregation, etc. From a purely genetic point of view, the analysis of these phenomena constitutes the most interesting part of this work, but it has no special relation to the problems here under discussion.) Back crosses, however, give a 1:1 ratio. The following table gives a few data of this kind.

TABLE III

Breed	F_2 From	Dark, Per Cent.	Light + Medium, Per Cent.
WA12...........	S×K	23.8	76.2
WA13a..........	K×S	25.5	74.5
WA24b..........	S×Ky	25.9	74.1
WA28a..........	A×S	25.3	74.7
WA31...........	O×S	26.2	73.8
WA18...........	S×H	30.2	69.8
ZA20............	O×M	22.1	77.9
ZA9.............	M×H	25.8	74.2
ZA12............	G×M	25	75

[1] We give here a few random examples. The amount of actual material is very large, as more than 100,000 caterpillars have been bred and studied. We refrain, furthermore, from all such details as behavior in reciprocal crosses, etc.

The actual curves look like the example in Table IV of an F_2 cross.

TABLE IV

ZA9 F_2 FROM M × H

	I	II	III	IV	V	VI	VII	VIII	IX	X
Individuals	24	..	..	..	13	9	29	15	3	..
Per cent	25.8	..	..	..	14	9.7	31.2	16.1	3.2	..

The sum of all the hundreds of curves shows that we are dealing here with a case of multiple allelomorphism: The pigment factor, producing the gradual covering of the markings, is present in the different races in different degrees, all being allelomorphic to each other.

Thus far we have dealt only with the very young caterpillars. Their further history in regard to the effect of these factors leads us one important step further. We find mainly the following types of behavior within the pure races: (1) Light marked caterpillars, which remain practically the same throughout the entire larval life. (2) Light-marked caterpillars which grow darker with every moult and finally are about medium or more than medium dark. (3) Light-marked caterpillars which change during the larval stage, so that they finally are all dark. (4) Medium light caterpillars of different degrees changing to dark during larval life. In the following tables we give a few examples of these races, showing the shifting of the type of marking during the stages of larval life. The large range of variation after the third and fourth moult visible in these tables is due more to a different speed of shifting in different individuals than to the initial variability. This is shown in Table VI, which gives an example of the shifting of types of pigmentation during the larval stages for a series of isolated individuals of some of the pure races.

The genetic analysis of this phenomenon seems to reveal the real nature of the multiple allelomorphs, which cause these different types of pigmentation and their behavior during development of the caterpillars. With-

TABLE V

EXAMPLES OF SHIFTING RACES

Race H

Class Frequencies in Per Cent.

Stage of Caterpillars	I	II	III	IV	V	VI	VII	VIII	IX	X
3	..	..	..	..	..	..	..	38.6	54.5	6.9
4	..	..	..	..	..	11.8		55.3	31.7	1.2
5	29.3	24.4	9.7	12.2	9.8	12.2	.	2.4	..	..
6	64	16	16	4	..	..	..	..	..	..

Race A

Stage of Caterpillars	I	II	III	IV	V	VI	VII	VIII	IX	X
3	..	..	..	..	19	43	38	..	..	..
4	..	..	..	..	35.5	58.1	6.4	..	..	..
5	14.3	42.9	4.7	9.5	28.6	..	..	..	..	..
6	100			..	..	..	..	..	..	..

Race G

Stage of Caterpillars	I	II	III	IV	V	VI	VII	VIII	IX	X
3	..	..	..	..	..	..	11.8	57	31.2	..
4	..	..	..	..	1.4	35.2	33.8	28.2	1.4	..
5	3.6	7.2	14.4	18	25	22.8	9	..	..	..
6	100			..	..	..	..	..	..	..

TABLE VI

EXAMPLES OF SHIFTING AS OBSERVED IN INDIVIDUALS WITH DIFFERENT NUMBER OF MOULTS

Race	Individual	Class of the Individual after Moult					
		2	3	4	5	6	Sex
H	ZA3.6	IX	VII	II			♂
"	ZA3.7	VIII	VII	I			♂
"	ZA3.4	IX	III	I			♀
"	ZA3.1	VIII	VII	I	I		♀
A	ZA4.1	VI	V	III			♂
"	ZA4.3	V	III	I			♂
"	ZA4.4	VI	VI	IV	I		♀
"	ZA4.8	VII	V	III	II		♀
"	ZA4.13	VI	V	IV	I		♀
G	ZA6.11	VIII	VIII	VI	II		♂
"	ZA6.7	VIII	VI	VI	IV		♂
"	ZA6.5	VIII	VIII	VI	III		♀
"	ZA6.6	VIII	VIII	IV	III	I	♀
"	ZA6.17	VIII	VI	V	III	I	♀

out going into details, which would necessitate a multitude of tables and curves being given, the following points

are of importance: (1) F_1 between a non-shifting light race and an always dark race is intermediate, or somewhat lighter in the beginning. But by progressive stages the hybrid caterpillars shift over into the dark classes.

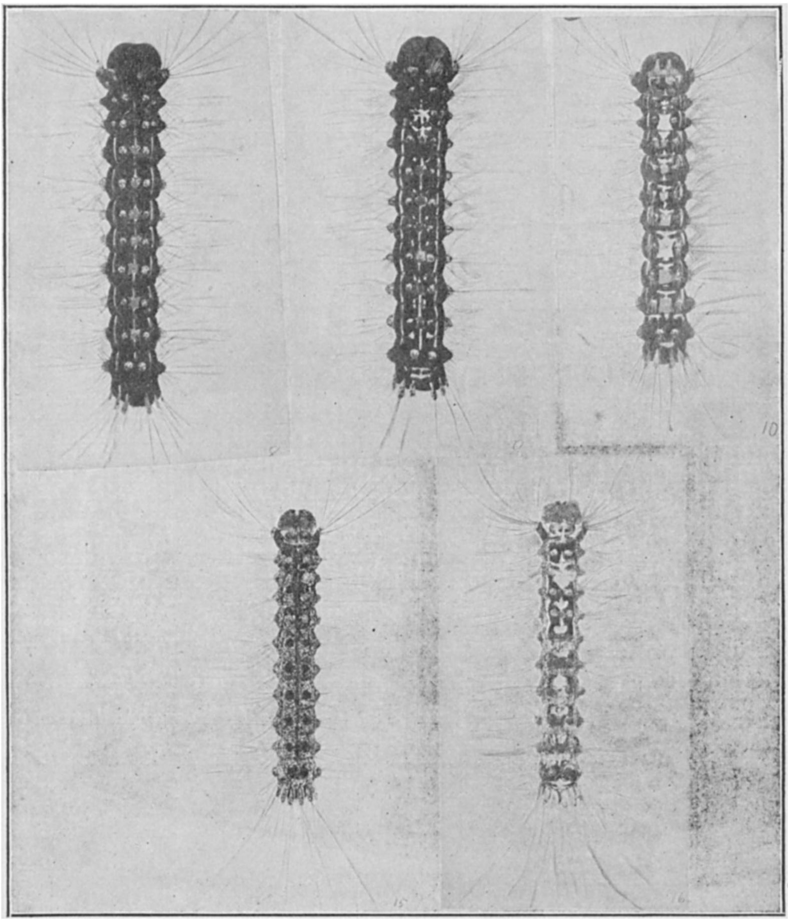

FIG. 2. First row: hybrid between the two parental races after second moult. Second row: Hybrid (left) and light parental race (right) after fourth moult. Drawings by Dr. Poppelbaum, 1912.

Fig. 2 represents caterpillars from a cross of this type. (The exact curves that belong with these pictures are reproduced in our "Einführung in die Vererbungswissenschaft," 2d edition, 1913, p. 170, Fig. 66, as an example

of change in dominance during development.) (2) The same thing happens in certain F_2 crosses, reversing completely during larval life the original ratio of lights and darks. (3) The different races involved are characterized by a difference in the speed of differentiation, as shown in the actual curves. This velocity is also caused by genetic factors. Where these recombine with the pigmentation factors, the entire situation of the F_2 curve is shifted (without changing the 3:1 ratio), showing that the visible effect of the pigmentation factors is bound to a certain velocity of differentiation. (4) The shifting of the type of pigmentation from light to dark during larval life of certain races or hybrids is a process which progresses constantly with time. This is seen when isolated individuals are studied which belong to races that differ in regard to the number of moults and exhibit the shifting simultaneously. There are races where all the male caterpillars have four moults and the females either four or five; other races where the males have four, the females five; others where both sexes have five moults; and in the last case even a sixth moult occasionally occurs. In these cases we see that every new moult produces a further shift to the dark side of the curve, showing that the class of pigmentation to which a full-grown caterpillar belongs is in this case a function of the time of differentiation. The same fact can be demonstrated in a shifting race by prolonging the time between two moults by starvation (which succeeds only to a certain extent). In experiments of this sort it has been possible to get the shifted type of pigmentation, characteristic of the fourth stage, in some individuals in the third stage. Table VI also contains a few random data on the first point. (6) In shifting hybrid cultures there appear comparatively often mosaic-caterpillars, showing different classes of marking on right and left sides. The distance between these two different classes is approximately kept up when shifting occurs during development. The following example demonstrates this fact:

TABLE VII

	Class After Second to Fifth Moult							
	2		3		4		5	
	Right	Left	Right	Left	Right	Left	Right	Left
WA51, 27	IV	III	IV	II	III	I	I	I

These caterpillars always give normal moths and normal offspring.

A careful consideration of these points shows clearly what these multiple allelomorphs for pigmentation really are: They are different quantities of the substance which we call a gene which act according to the mass-law of chemical reactions, *i. e.,* produce a reaction or accelerate it to a velocity in proportion to their quantity. In our special case it means that the factor stands for a metabolic

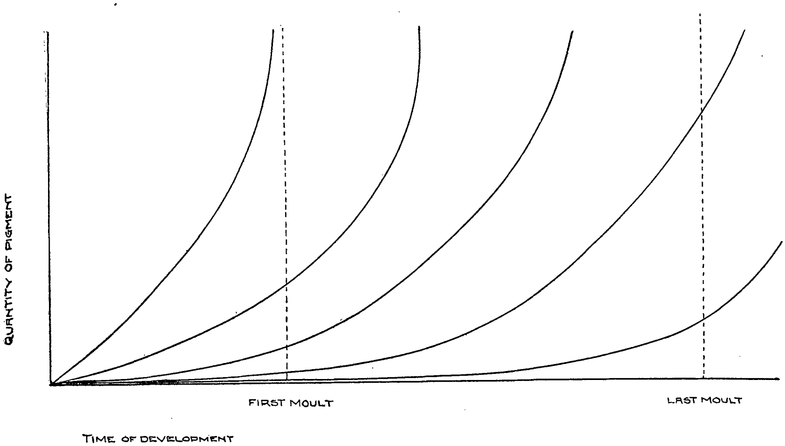

FIG. 3.

activity proceeding with a definite velocity dependent upon the quantity of the factorial substance present. This activity finds its visible expression in the deposition in the skin of increasing quantities of certain products of protein decomposition which as chromogens are oxidized into melanin pigments. The effect of the different quantities of active substance (enzyme?) which we call the multiple allelomorphs upon the progressive pigmentation

of the caterpillars is then represented by the graph on p. 36 (Fig. 3).

Given a definite quantity of the factorial substance and identical conditions, the velocity of the reaction is constant. Thus the final result depends upon the amount of the factorial substance present and the independently inherited rapidity of differentiation, which determines the situation of the growth-stages on the abscissa (the dotted lines). Thus the above quoted facts as well as the multitude of details not mentioned can be easily derived from this graph. The last named mosaics are of course the expression of small differences in the velocity of differentiation in symmetric halves of the body, which are well known to embryologists.

These conclusions in regard to the real character of multiple allelomorphs are the same as those derived from other characters in the same objects. In our work on intersexuality we were able to prove, to as great an extent as a genetic proof can possibly be carried, that the different geographic races of the same moth differ in regard to the absolute and relative quantities of the substances, which we call the sex-factors. In the genetic language of the present day we should call them, therefore, multiple sex-allelomorphs, a conception which indeed we have always used (without this recent term) since our first report about this work in 1911. In the case of intersexuality we can furnish facts very similar to those about the caterpillars, if we consider certain features of the wing colors. In normal males a certain amount of pigment covers the entire wing, whereas the female wing is unpigmented. This pigment is formed by the oxidation of a chromogen deposited within the scales. There it flows from the wing veins with the blood. By a detailed analysis we are able to show that an intersexual male is a genetic male which developed as such up to a certain point when the development suddenly began to continue under the aspects of femaleness. One of the results of male metabolism is the production of these chromogens

in late larval stages. This production is therefore stopped when female metabolism sets in; when then the time arrives in development, when the chromogen spreads over the wing scales, its available amount is proportional to the relative lateness of the reversal of sex. Therefore, with increasing intersexuality, the pigment flowing from the veins covers a smaller and smaller area of the wing, finally being confined to the neighborhood of the veins. As[2] the analysis of the other intersexual organs allows an accurate determination of the time factor involved, we have here a very close physiological parallel to the facts about the caterpillars.

In most other cases of multiple allelomorphism only the results can be seen, and it will be difficult to work out the time factor, which proves that the multiple allelomorphs are different quantities of an active substance. (Some botanical subjects ought, however, to be favorable.) But in comparing the other facts about multiple allelomorphs with our cases, we feel confident that, whereever a similar analysis can be applied, the results will be the same. For example, all the cases of quantitatively different pigmentation, which are of multiple allelomorphic nature, like Castle's hooded rats or our different cases of melanism in moths, show that the effect of the different factors is that different quantities of pigment spread from different "points of outlet," which of course are hereditary traits of the species or group; the similar effect, therefore, leads to suspect a similar cause.

If our conclusions regarding the nature of multiple allelomorphs are accepted, it must lead to a different intellectual attitude toward the problem of variability of genes, which is so important for evolution. The opposition to the view has been, we believe, primarily on aprioristic grounds. In the long controversies of recent years regarding the interpretation of Castle's work the logical side of the case seems to have always been in the foreground. The same is the case when E. Baur calls our

[2] See pictures in *Jour. Exp. Zool.*, 22, 1917, pp. 614–15.

views in regard to the variability of the sex-factors *a priori* inadmissible. We believe that this intellectual attitude toward the problem is the result of Johannsen's doctrine of agnosticism in regard to the nature of the gene, which resulted in a kind of mystic reverence, abhorring the idea of earthly attributes for a gene. (Our distinguished opponents will excuse this somewhat extreme statement.) If, however, it can be proven that genes are substances with the attribute of definite mass, it would be illogical to deny their variability. Nobody will claim that a gene is a substance that passes unaltered from generation to generation. The elementary facts of development and regeneration show that this substance grows, at least, and increases in quantity. If, now, the substantial basis of heredity in the sex-cells is established by the assembling of all the factor-substances in their characteristic quality *and their correct quantity,* the situation is the same for the gene as for any other organic process: the varying conditions of the surroundings of the gene cause a certain amount of fluctuation in its quantity. This conclusion entirely changes the logical aspect of the question, whether or not a change of the gene by selection of variants is possible.

The strongest point of the anti-selectionists was that it is absurd to assume that a selection of somatic fluctuation has anything to do with the characters of the germ-plasm. With the quantitative view, however, which we believe to have proven in two elaborate cases, this situation changes. The somatic character in question, say amount of pigmentation, can only change toward a plus or minus side. This change is caused directly by a difference in the velocity of the reaction of some metabolic process which results in the deposition of pigment. Such a change of velocity of reaction, however, can be produced either by the action of the medium, and then it is a modification, or by fluctuation in the quantity of the gene, causing increase or decrease in the velocity. The resulting variation is of course, phenotypically, the same. Selection, therefore,

may be ineffective, if a modification only is selected; it will be partly successful if a combination of plus-quantity with plus-modification is selected; and fully successful if the exclusive result of plus-quantity of the gene is selected. The *deus ex machina* modifying factor, which, moreover, does not fit the decisive genetic facts in the most discussed case of Castle's rats nor our cases, thus becomes superfluous.

It is, moreover, perfectly logical to assume that selection of either plus or minus quantities of the genes changes the mode of the fluctuation of this quantity correspondingly in the succeeding generation. If the different quantities of the substances, which constitute the systems of multiple allelomorphs, are inherited, then every other quantity is also inherited. If the presence of the quantity p in the germ cells of the parents causes the reappearance of the quantity p in the germ cells of the children, the same fact applies to the quantities q, r, s—to every quantity which is present or has been selected. Selection can, therefore, change the quantity of the gene, and also, therefore, the somatic characters caused by quantitative differences in the gene, until the physiological limit is reached. This limit may be the limit for the character in question—for example, no pigment, self-color—or it may be the limit set by the necessary coordination of developmental processes. For example, in the development of a moth a certain gene causes, at a certain moment—during pupation—the evagination of the imaginal disks of the antenna. The correct quantity of the gene causes this process to take place at the correct time. A quantitative variation of the gene would cause the evagination to take place at the wrong time. We have, indeed, had strains of caterpillars where in many individuals this process took place in the last stage of the caterpillar, giving caterpillars with pupal antennæ. The quantity of the gene in question was in these cases not coordinated with the other genes and the action was produced too early. It is evident that quantitative changes

of this kind will lead to physiological impossibilities, monsters, etc. Here, then, is again the limit for selection of factorial quantities. It need hardly be added that such selection is necessarily orthogenetic.

Our own experiments in this line are, as far as they go at present, in perfect accord with Castle's work. We have, moreover, applied another type of experimental test, namely, selection in F_1. If a given pair of multiple allelomorphs differs in regard to the quantity of the factorial substance and this quantity is subject to fluctuation around a mean, the variability of the character in F_1 is caused by the usual agencies producing fluctuations as well as by the different combinations of the parental quantitative values. Selection in F_1 ought, therefore, to influence the curve in F_2 in a certain number of cases, namely, when the plus or minus individuals are genetically plus or minus. Within the normal segregation of light and dark individuals in the 3:1 ratio a shifting of the mean for lightness and darkness must take place. In a series of such experiments we had a number of positive results. The following Table VIII may serve as an example:

TABLE VIII

F_2 WITH SELECTION IN F_1 FROM CROSS K × S

	In Third Stage									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Plus selection	25.5	..	..	7.3	12.7	9.1	30	15.4	..	..
Minus selection	25	5.7	26.9	15.5	17.2	3.2	6.5	..	..	..

We believe that these facts and interpretations have a definite bearing on the problem of evolution. The first step in the differentiation of species which occurs in nature seems to be the formation of geographic races. The entire bulk of modern evidence in ecology tends to show the existence of clearly defined local forms for very restricted areas. For example, the ichthyologists differentiate forms of Salmonids and Coregonids for practically every river and lake; in the same way in the lower

organisms, like Daphnids and Rotatoria, different forms appear in different regions. The ornithologists describe different races for every river basin of the affluents of the Amazonas; the mammalogists do exactly the same thing for every area which was thoroughly covered. Where breeding experiments have been carried on it has been shown that the geographic races may be perfectly fertile with each other and may produce fertile offspring. In some cases, however, the transitional stages toward sterility are found. Thus the production of intersexual moths in crossing geographic races can be regarded as a step toward increasing incompatibility, which in one of the crosses attempted by us was an absolute one. In other cases only a small percentage of the offspring of the hybrids could be reared, as in the crosses of the North and South European *Callimorpha dominula*. We, therefore, with many evolutionists, feel convinced that the geographic races are the most important visible steps in species-formation in nature.

If we now look into the characters distinguishing geographic races, we very often find certain qualitative differences most conspicuous, for example, exchange of red and yellow color in the moths. A close study of definite examples, however, reveals that these differences are often more conspicuous than important. This is shown by the only group of information in the animal kingdom which we have both by ecological and genetic work—the geographic variation of land snails. The facts about the extreme variability of *Helix, Achatinella, Partula,* etc., are well known, as well as the irregularities in the confinement of definite types to definite localities. We have been so fortunate as to gain some insight into these facts through a very interesting collection which Dr. Haniel made in Timor and studied under our direction (not yet published). It was evident here, as in the other cases, that a series of unit factors for number, color, form of bands and ground color, which recombined freely, was involved. And practically all the combinations could be

reduced to the genetic factors which Lang worked out for *Helix*. But, exactly as in the classic cases, there was no possibility of stating a definite relation of these factors to the grouping according to localities. In some localities certain factors or combinations did not occur, but the attempt to classify the material along this line proved a failure. However, every group from each locality exhibited beside these factorial recombinations certain quantitative characteristics of size, proportions, etc., of the shell which were characteristic for definite localities. These, however, are the characters which probably fall in line with those caused by the quantity of the genes.

The difficulties which the facts of geographic variation create for the conception of species-formation by selection have often been discussed. Bateson in particular ("Problems of Genetics") scrutinizes them from the modern genetic point of view. They are indeed insuperable if all characters which show variations and recombinations are considered from this point of view. The extreme irregularity, for example, of the local combinations of types of shells in *Helix, Partula* and *Achatinella* makes it impossible to regard them as local adaptations. This is certainly true, but may be without any bearing on the species question at all. The factors and recombinations occurring in *Helix, Achatinella* and *Prodromus* are more or less the same, just as are the recombinations of coat colors in different rodents. They constitute a set of mutations and their recombinations which are proper to the type of germ-plasm of the group. They occur, recombine or fail to appear as chance wills, and seem to have no special selective value. We do not think that these are the characters which play a part in the evolution of species; they are, in most cases, independent of adaptation.

There are, however, reasons for supposing that such differences of characters as are based on the quantitative differences of the gene are those which are influenced by selection and are important for the formation of the first

steps toward diversification of species. We base this opinion on the following facts:

One of the few cases where selection in nature has apparently been seen at work under our eyes is the much-quoted case of melanic moths. We started in 1908 to work out the case of the nun, *Lymantria monacha*. The dark varieties of this moth have been known as rare occurrences for over a century. But only during the last decades have they spread and almost replaced the white forms. The analysis of the genetics of this case shows that the dark form is a dominant mutation to the white and that the many different stages of darkness, which form a complete series from white to black, are produced by sex-linked multiple allelomorphs. (Unfortunately, the interesting details can not be given at present.) How is it, now, that these combinations have come to replace the original form? Many hypotheses, some of them very strange, have been put forward; but it seems to us that the case is comparatively simple. The dark forms are stronger, more lively, better fliers, as far as we can tell from our experience with the animals in captivity. They are also larger (see Fig. 102, p. 267, in our "Einführung in die Vererbungswissenschaft," 2d ed., 1913). The melanism is in this case, therefore, only the most conspicuous superficial feature of a quantitative and progressive change in a gene which causes a definite metabolic condition, resulting in hardiness as well as in the deposition of more pigment in the wings. The quantitative change has here a superficial expression and is therefore easily recognizable. But this visible pigmentation is not the really important character. How is it, then, that these melanic forms, and other forms in similar manner, have established themselves so suddenly? We may venture to point to the facts that the selection, as has often been stated, has occurred especially near the larger cities, and that the period during which this selection has taken place is the period of industrial development, *i. e.*, of restriction of forested areas near the cities. It is,

furthermore, the period of scientific and intense forestry and of economic entomology. Here we have the probable agencies that made life difficult for the moth and gave a great selective value to that advance in hardiness which lies behind the melanic appearance.

We should point out here the difficulties which arise in the criticism of definite views of evolution on the basis of facts not analyzed genetically. The selective value of a climatic character may often be doubted on the ground that the same type occurs in a very different area admixed with the local form. But genetic analysis may often show that what appears to be the same type is in reality a different thing. The north European Arctiid, *Callimorpha dominula,* has wings marked with red; the Italian form has wings marked with yellow. In certain localities (one of them near Berlin) a yellow sport of the red form regularly appears, apparently the same form as the Italian one. We, as well as others, have crossed these forms. The yellow sport is a simple recessive to red and segregation occurs in the 3:1 ratio. The Italian yellow form, however—at least the ones from the Abruzzi, which we used—crossed with the red northern form, produces intermediate orange in F_1 and in F_2 every shade from red to yellow. The two yellows, which look alike and probably are chemically alike, are nevertheless products of a different metabolic process. In the sport the same metabolic process which usually leads to red pigment is changed by mutation only to the extent of the color change in the end-product. In the southern form a different type of metabolism results in the formation of yellow pigment, and the cross is therefore an entirely different cross, with different results.[3] As a matter of fact, the latter cross shows very much diminished fertility, as Standfuss has already pointed out. This shows how unsafe the ground is on which criticism of evolutionary questions without genetic test is based. That our example is not an exception is proved by the fact that Standfuss long ago formu-

[3] We may point out that herefrom a rational interpretation of dominance and blending can be derived.

lated the rule, that when two forms coexist in the same locality and are able to interbreed, they do not produce intermediates; but when the forms are geographically separated as local races, crosses between them result in a series of intermediates. Bateson says: "In this aphorism there is a good deal of truth." We think that the rule expresses the difference between a non-adaptational chance mutation and the adaptational change in the factorial quantities which may lead to a similar-looking, but physiologically different character. This character, although, like the non-adaptational one, is itself of no selective value, is the result of a general physiological change which does have a selective value.

This will become still more evident if we return once more to the study of the gypsy-moth. In studying the relations of the different geographic races as characterized by the multiple-allelomorphic characters in question, we find that these characters are paralleled closely by differences in the life-cycles. Without going into details, we may state as a fairly general rule that the races with high degrees of pigmentation in the later stages are the ones which show a fast development, comparatively short larval life and a long period of hibernation. The light races have a comparatively long larval period and a correspondingly short period of hibernation. The former races, furthermore, inhabit the areas where a long and cold winter occurs, while the latter are endemic in places which have a hot summer, early spring and mild winter. One might think that these different characteristics were simply the direct effect of temperature conditions. But that this is not the case is shown by the constancy of the differences when the races are bred in a different climate and also by experiments on the physiology of hibernation, which have convinced us that the time relations of the life-cycle are—of course, within the limits of fluctuation—a heritable trait of rhythmic character. These facts show where the adaptational character of the differences of the geographic races lies: the adaptation which fits the differ-

ent milieus is the life-cycle (in a broad sense). The visible distinctive characters of the races—aside from additional mutations of a non-selective nature—are nothing but the products of reaction of different types of metabolism, allied with the different time relations of the cycle. The method of the formation of geographic races in this case must, therefore, be the following. The first conquest of a new territory is of course only possible when the animal is preadapted, along general lines, to the new medium. But that it can maintain itself depends upon its power of special adaptation. The gypsy-moth, for example, has repeatedly been brought into England, but it has never established itself there. In the case of this form the special adaptation means the coincidence, in the first place, of the life-cycle with the seasonal cycle in nature. And it is here that all the discriminating effect of selection comes in. The quantitative changes of the genes which cause the time relations of the cycle are then the material for selection, and selection acts according to Darwinian principles until the equilibrium is established. Thus the genetic study of the quantitative changes of the gene reveals anew the truth of Darwin's conception. Furthermore, we see here how sterility of hybrids or complete incompatibility of new forms may arise. We have proved that the quantitative differences of the sex-factors, which are themselves nothing but adaptations to the time-relations of the cycle, are among the characteristic differences of these races.[4] There are, moreover, responsible for the incompatibility in regard to sex which results in intersexuality after crossing. Changes of exactly the same type may easily make any cross-breeding impossible, since no organism can develop unless all the processes of differentiation are coordinated in respect to their velocity. Here we see, finally, why geographical races are so often uniform and are characterized by certain traits of

[4] Compare also Pflüger's and R. Hertwig's work with frogs and Cuénot's with starfish, demonstrating similar facts in regard to geographic variation of sexuality.

a quantitative character even when additional mutations and their recombinations make them at first sight appear diversified. This uniformity indicates the adaptational type produced by selection of the quantitative variations of some vital gene; the differences are only a difference in apparel.

In conclusion, we may point out three groups of facts which, of the greatest importance for evolution, have always been a hard nut for the mutationists to crack. The first is the series of temperature-experiments in Lepidoptera—and similar experiments in Amphibia, Crustacea, etc.—that lead to the production of aberrant forms which resemble closely certain geographic varieties. But, with the exception of certain often-quoted cases, these aberrations are not hereditary. In the light of our experiments these facts are not surprising. The effect of the temperature experiments is to change the normal time-curve of certain metabolic processes. The effect is, therefore, due to this change of one of the variables of the reactions in question. The quantitative change of the substance of a gene, however, which we found to be at the basis of the geographical variations, also produces a difference in respect to the time-curve and therefore the same effect, this time a heritable effect. If we now select the plus individuals in this type of experiment—and this applies to all analogous experiments—we may simply select a modification. But we also may select the combination of a plus-modification with a plus quantity of the gene in question. If the experiment is repeated, the next generation will then show a still stronger reaction, or, if the experimental influence is not repeated, there will be an after effect of the experiment on the parents. It is remarkable that such results, which were to have proved the inheritance of acquired characters, always turned out, when characters relating generally to the life-cycle were in question, characters which also appear in the geographic races of the form. Extreme mutationists used to deny or disregard these facts. Here we have a simple

explanation for them which both does justice to the facts themselves and falls in line with modern genetic views.

Furthermore, we now see the exact meaning of Darwin's view, which he had to express in a somewhat ambiguous way on account of the lack of experimental data which would have permitted clearer expression. His essay of 1842, the forerunner of the "Origin of Species," begins with the words: "An individual organism placed under new conditions sometimes varies in a small degree and in very trifling respects, such as stature, fatness, sometimes color, health, habits in animals and probably disposition. . . . Most of these slight variations tend to become hereditary." This statement shows clearly what Darwin had in mind. If he assumes that some variations, which are produced by change of conditions, are sometimes non-heritable, but tend to be inherited, we can now explain what this means. The variations which, as geographic races, form the first steps in the formation of new species are indeed exactly the same whether or not they are inherited. Their direct physiological cause is also identical, being a change in the rate of a definite process during differentiation. Only the ultimate cause is different; in the one case the original quantity of the gene determines the rate of differentiation—which then is hereditary—from the beginning; in the other case an outside factor is active, retards or accelerates the same reaction to the same degree. With this additional bit of interpretation, Darwin is right, after all.

The other group of facts includes certain details of mimicry (mimetism). We believe that the general principle of mimetism has been fully explained genetically by Punnett. But there are certain details which his selectionist opponents point out which constitute strong evidence against Punnett's view. We think that the most valid argument against the Mendelian view of mimetism has been derived from the facts about the parallel geographic variation of model and mimic. If our genetic conception of geographic variation is correct, this point

is not difficult to understand. If the resemblance of model and mimic is based on the presence of similar chance- or non-chance combinations of genetic factors, and if geographic variation consists in the specific adaptation of the quantity of certain genes to a required velocity of some vital reaction, it is very natural that similar genes in model and mimic should be in exactly the same situation and should undergo parallel changes.

The third important set of facts to be considered is the problem of domestication. Darwin's view is well known, as well as the solution of a great part of the problem through Mendelism. The latter shows that selection of the recombinations after cross-breeding (besides picking of mutations) is the chief source of success in domestication. (See our demonstration of this fact regarding the improvement of pigs in "Einführung in die Vererbungswissenschaft," 2d ed., 1913, pp. 276–80.) That this fact was well known to Darwin is shown, for example, in his report about Lord Orford's greyhounds ("Variation of Animals," etc., Ch. 1). But he believed, in addition, in a positive effect of selection of small variations. Wherever he tabulates such characters, most or all of them are quantitative characters of a kind which we can assume to be dependent upon the presence of definite quantities of a gene. Here we may have the solution of the difficulties which the problem of domestication affords in spite of mutation and recombination. No doubt the high capacity for fattening was crossed into our hogs with Asiatic forms. But selection of plus-quantities of the responsible gene enabled us to obtain the character as it stands to-day.

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